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Technology and Risk Assessment Using a Robust Design Simulation Methodology

Phase I - Definition and Initial Implementation of RDS

Progress Report

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Highlights of Phase I

Robust Design Methodology Development and Implementation

Methodology Implementation into the Curriculum:

This year we were able to implement the Robust Design Methodology developed at ASDL into our aerospace engineering graduate design curriculum by having this year's design team execute the methodology for their team project. The project was focused on the preliminary design of an HSCT concept, and more specifically, the development of a design configuration that is insensitive to variability induced by the economic environment it is operated in.

This work is summarized in the proceedings of this year's ASDL external advisory board symposium held at Georgia Tech in May 1996 (proceedings have already been mailed to sponsor) and a 300 page final report submitted by the team which will be mailed to you separately.

Mission Requirement Analysis for an HSCT, using the RDS Methodology

As part of the methodology development and implementation, an investigation was conducted as to how this technique (RDS) may be used to identify how stringent the design requirements of a proposed vehicle may be and assess their sensitivity to variations (the goal here will be their possible relaxation). The study focused on the effect of mission requirements on the economic robustness of an HSCT concept. The results of this work were published and presented at the conference of the International Society of Parameter Analysts in Cannes, France. The paper was received well and was awarded best paper. Some of the key findings included the introduction of a new approach to robust design by forming an Overall Evaluation Criterion (OEC) comprised of the variance and mean of the objective function distribution. A minimized OEC yields a robust design, while the formulation of the OEC depends on the objective function (see Appendix I). The selected example of an HSCT configuration showed the dependency of $/RPM, DOC, and TOC on design parameters like Thrust-to-Weight ratio and Wing Area, mission parameter like Design Range, %-Subsonic Mission, and Number of Passengers, as well as economic parameters such as Fuel Cost, Load Factor, Utilization, and Economic Range. The paper demonstrated how the variability in $/RPM, introduced by the economic parameters, can be reduced by changing the mission and design parameters. Hence, a robust solution within the range of the parameters was identified and presented. A detailed description of the robust design methodology execution can be found in Appendix I.

Paper was submitted to sponsor and is included here again for completeness sake.

Integrated Design and Economic Analysis/Optimization Study

In a second paper, presented at the AIAA/USAF/NASA/ISSMO Multidisciplinary Analysis and Optimization Conference in Seattle, WA, a different approach to obtaining robust design solutions was presented. According to this approach a target for the objective is selected along with a set of design ("control") and economic ("noise") variables for the objective function(s) (e.g. $/RPM) and a set of appropriate constraints. This method fits by trial and error a series of suitable distributions (i.e. gamma, beta, normal, lognormal, etc.) to the actual objective function histogram distribution (as obtained by the Monte Carlo simulation) and identifies the dependency of the probability of achieving the target value to the design variables. Again, a robust design solution was found for the selected HSCT example subject to such constraints as a fuel requirement, approach speed, landing and take-off field length. The advantage of this method is that it directly links the design parameters to the decision makers objective: probability of success in form of meeting the target. A detailed description can also be found in the appendix of this report (Appendix II contains the aforementioned MDO paper).

Aerodynamic Optimization of an HSCT using Response Surfaces

The third paper, presented at the 20th Congress of the International Council of the Aeronautical Sciences in Sorrento, Italy, concentrates on the expansion of the conceptual design tool FLOPS to a multidisciplinary preliminary design tool utilizing the Response Surface Methodology. It explains in detail the approach and executes the HSCT concept as an example. This example embodies a screening test of aerodynamic variables affecting the drag polar equation and a Response Surface Equation (RSE) generation with the most influential variables, based on the previously performed screening test. By employing this aerodynamic RSE for the HSCT concept in FLOPS a constrained aero-propulsion optimization is carried out. It identifies the wing planform and engine parameter setting that minimizes the required average yield per passenger mile ($/RPM), while satisfying all imposed constraints, such as approach speed, landing and take-off field length, and sideline plus fly-over noise. This paper is also included as an appendix at the end of this document.

Design for Reliability

Probabilistic Design for Reliability using the FPI Technique

The Fast Probability Integration (FPI) technique is a probability estimation method based on the Most Probable Point (MPP) analysis. This technique has been developed by the SouthWest Research Institute (SWRI) for the Structures division of NASA Lewis Research Center. The purpose of this method was to facilitate the reliability prediction of aircraft engine turbomachinery components. The FPI technique is directly applicable and integrateable to the proposed approach and is thus considered for further development. More specifically, the MPP analysis utilizes a response function Z(x) that depends on several random variables x (see Figure 1 for a 2-D example). Each point in the "design" space spanned by the x has a specific probability of occurrence according to the x's probability distribution function (pdf) (see Figure 2). However, each "design" point also corresponds to one specific response value Z. Hence, each response value has the same probability of occurrence as its "design" point.

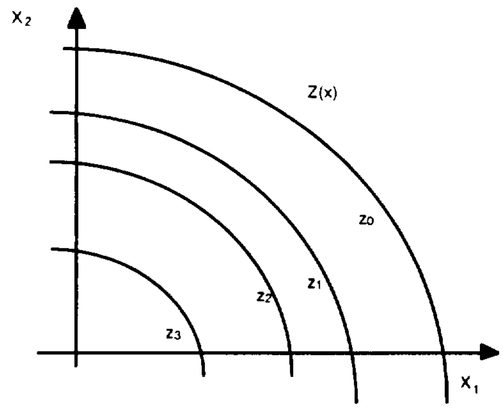

Figure 1 : Contours of Objective Function Z(x)

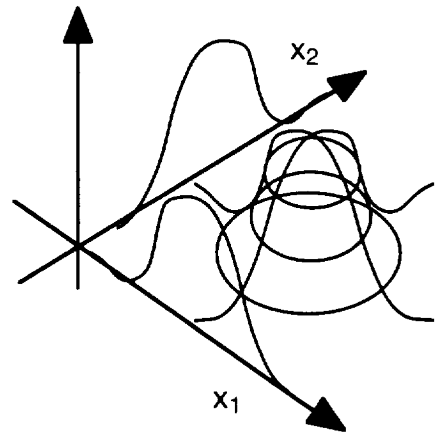

Figure 2 : Joint Probability Distribution

In reliability analysis and other disciplines involving random variables it is often desired to find the probability of achieving response values below a critical value of interest. This critical value can be used to form a limit-state function (LSF) $g(x) = Z(x) - z_0$ where values of $g(x)$ 0 are undesirable. The MPP analysis calculates the cumulative probability of all "design" points that yield $g(x)$ 0 (or $g(x)$ 0) for the given z_0 (see Figure 3). Since the LSF 'cuts' off a section of the probability value (see Figure 4) a "design" point with maximal probability of occurrence can be identified on that LSF. The point is called the MPP.

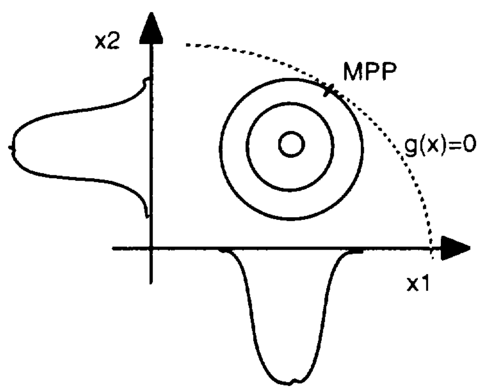

Figure 3 : Most Probable Point (MPP)

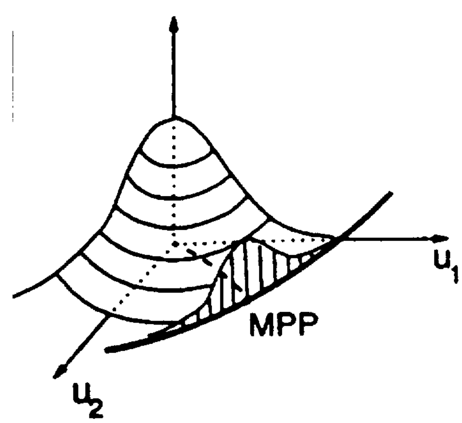

Figure 4 : Visualization of MPP

The FPI code, developed by SwRI, who's short course I attended, offers several techniques to find the MPP and the probability of a given LSF value z_0 for the response function. Some of these techniques are very efficient and might eliminate the need for an expensive Monte Carlo Simulation. An additional advantage of FPI is the fact that it is directly linked to the analysis code, eliminating the need for an response surface equation. However, FPI does approximate the LSF locally at the MPP.

The FPI method can easily be adopted to our probabilistic design methodology, where Z(x) is the objective function and z_0 a desired target value. An extension of this method, also proposed by SwRI, is the assumption of z_0 as random variable, also dependent on the same noise variables. A readily available example cost estimation can be constructed with Z being revenue and z_0 being cost. The difference $g(x) = Z(x) - z_0(x)$ would be the profit and a $g(x)$ 0 is desirable. This example is illustrated in Figure 5, where the shaded area indicates the cases of a loss and its probability.

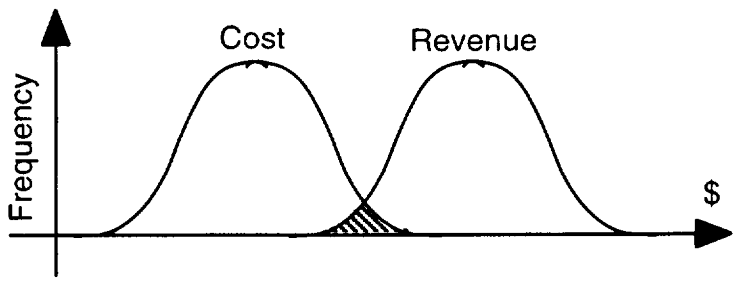

Figure 5 : Probability of Profitability. A proposed example to illustrate the applicability of FPI

Meeting with Dr. Christos Chamis, NASA Lewis:

A four day meeting with Dr. Chamis, Chief Scientist at the Structures Division, NASA Lewis Research has secured access to a code called NESSUS that is capable to perform structural analysis of engine components in a probabilistic fashion. The FPI routines are a subset of this code. Dr. Chamis has agreed to share this code with ASDL. What is proposed here is to remove FPI from NESSUS upon delivery, make these routines into a stand alone code and integrate to a variety of codes to allow for probabilistic solution. An integration with ALCCA will be the preferred first exercise.

Meeting with GE for Joint Effort Design for Reliability and Support with Data:

During this first phase a series of meetings have taken place with General Electric Aircraft Engines to discuss the possibility of a joint collaborative effort in the areas mentioned above. According to these discussions, GE has agreed to provide guidance and data to us. COMPEAT their integrated design and economics program will become available to ASDL to form relationships (RSEs) for the various engine economic metrics. Furthermore, they will share techniques and technical expertise as to how GE performs reliability estimation of critical components as well as information on their on-going robust design simulation efforts.

Examined FPI Method and SwRI Component Reliability Analysis:

In the FPI reliability analysis, as described above, each limit-state function (LSF) corresponds to a component reliability. A system reliability analysis assembles several LSFs to a "feasible" design space (see Figure 6). An advantage of this method is the ability to distinguish between and and or type system recomposition. If, for example, in a three component system Component 1 and Component 2 have to fail for the system to fail, the area of interest with $g(x)$ 0 is decreased for both $g_1(x)$ and $g_2(x)$ (see Figure 6). If on the other hand Component 3 alone causes the system to fail, i.e. Component 3 or {Component 1 and Component 2} produce a system failure, the area of interest with $g(x)$ 0 is increased by the area of $g_3(x)$ 0. In addition to this system reliability approach, SwRI proposes a sensitivity analysis that is, however, not jet implemented but well documented. This sensitivity analysis assesses the change in probability with a change in one of the distribution parameters.

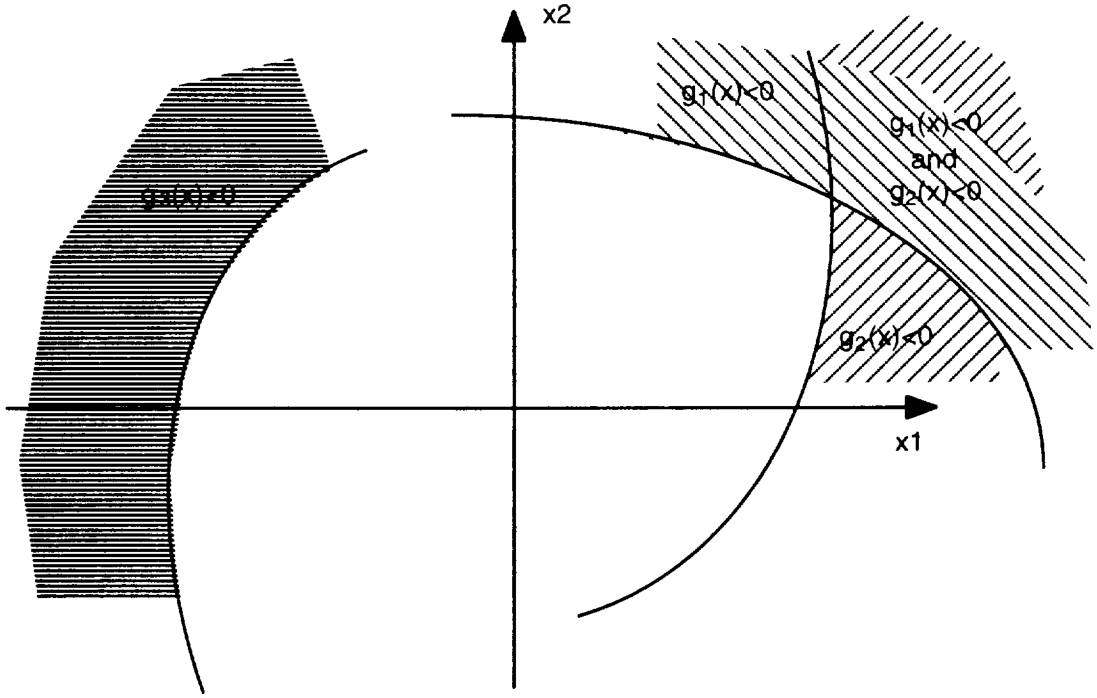

Figure 6 : Depiction of feasible design space in the presence of constraint functions

Cost/Cycle Time Reduction

Initial Literature Research Supported by Greg Bell, IDA:

Modification of TCM to Handle DOE and Monte Carlo Simulation:

Over the period of one year one of the graduate students transformed Greg Bell's (Mc Donnell Douglas) created Tailored Cost Model from a Lotus to a Microsoft Excel based workbook. The Lotus based program existed of a total count of 26 separate spreadsheets that were combined by a complex system of macros. The program had to be executed by hand for each run, i.e. combining the spreadsheets with each other. This process was extremely time consuming, approx. 20 min., and left room for a lot of human error in particular for the inexperienced user.

All 26 Lotus sheets are now combined in one Microsoft Excel workbook with five sheets containing the inputs, outputs, and CERs of the program. The macro structure had to be rewritten and facilitates now a print menu that allows the user to select a group of printouts for the outputs and/or inputs/assumptions of the cost analysis. However, the original structure of the code was conserved and its functionality was proven [see App. I]. This combination of 26 spreadsheets to one workbook reduced the run time by a factor of 50 to 100, from 20 down to 0.4 to 0.2 minutes, depending on the platform the program is running on.